NAVAL HEALTH RESEARCH CENTER

EYE MOVEMENTS DURING VISUAL AND AUDITORY TASK PERFORMANCE

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P-61.2: Eye Movements During Visual and Auditory Task Performance

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Abstract

The primary focus of this research effort was the tracking of eye movements during complex cognitive tasks. 8 volunteers performed a visual tracking task alone and a combination of the visual task and the auditory Paced Serial Addition Task (PASAT). Results showed a reduction in range on the order of 50% for eye movements and an increase in variability of vergence eye movements during the dual-task. This change can be characterized as visual tunneling.

1. Objective and Background

In optimization of the design of new systems and adaptation of existing technologies, the accurate measure and prediction of human operator workload can be critical. Within the context of a complex human-machine system, there is the environment, task, and operator state. It is the latter, operator state, which is the focus of this study.

Visual attention has increased in importance as the systems into which humans are being integrated become more visually complex. The ability of humans to attend to a variety of stimuli in these complex systems is often the limiting factor in overall system performance. Eye movement behaviour can now be detected by stand-off video cameras. Thus a system that could reliably detect eye movement behaviour patterns related to operator states such as fatigue, loss of attention or workload would be then able to alter the task presentation to optimize operator-system performance. In this pilot study we sought to extend the process of understanding, quantifying and modelling eye movement behaviours that are indicative of physiological and cognitive states.

Human eye tracking technology has experienced significant improvement in recent years in such critical areas as sampling. Further, reduced costs and improved reliability of systems makes it feasible to monitor both eyes and thus provide additional parameters to measure, a second eye and its correlation with the first eye. To date, many eye activity behaviours have been correlated with visual and cognitive demands of various tasks. What is lacking in the current body of literature are a variety of real time models of human operator state that can be integrated into system functions. In the present study we wished to examine measures of operator workload as indicated by oculomotor activity. We chose to combine a visual task (tracking an object) with an auditory task. A priori, the auditory task should have no direct requirement for change of oculomotor behaviour while it is being performed. Thus any changes in behaviour may potentially be ascribed to the increase in workload when going from visual alone to visual and auditory.

The participants were 8 volunteers who, while wearing the head-mounted eye tracker, performed a visual tracking task and a combination of the visual tracking task and auditory task.

A simulated screen shot of the visual tracking task is shown in Figure 1. The subject uses a joystick to center in two dimensions a visual target that is being constantly perturbed. This task is a reasonable proxy for simultaneous lane keeping and speed maintenance during driving.

The second task is an auditory task – a version of the Paced Auditory Serial Addition Test (PASAT). In this task the subject hears a series of numbers and must then add each number to the previous number and state the sum. Task difficulty is a function of number presentation speed. It can demand total attention from the subject at moderately fast speeds for successful performance.

We recorded eye movements through high-bandwidth, binocular tracking. The eye tracking system utilized in this study was the EyeLink II, from SR Research Ltd, Mississauga, Canada. Video-based eye tracking systems have long been acknowledged as the simplest to set up and operate. EyeLink II has a high resolution (noise-limited at <0.01°) and fast data rate (500 samples per second). This exceptional data quality results in very low velocity noise, making the EyeLink II ideal for saccade analysis and smooth pursuit studies. On-line gaze position data is available with delays as low as 3 milliseconds, making the system ideal for gaze-contingent display applications. In addition, on-line data parsing occurs, making eye events such as saccade, fixation, and blink available within 25 ms to the display computer.

We tested subjects performing each task independently and both tasks simultaneously. Our initial analysis shows it may be possible to discriminate between a visual and an auditory focus based on eye movements for independent task performance.

Subjects anecdotally reported that they felt they were doing the visual tracking task automatically and without attention. However, we found differences in eye movement behaviour when performing the visual tracking task alone and performing both tasks together. In particular, depth of field changes indicated that the subject was occasionally not fixated on the screen during the combined task.

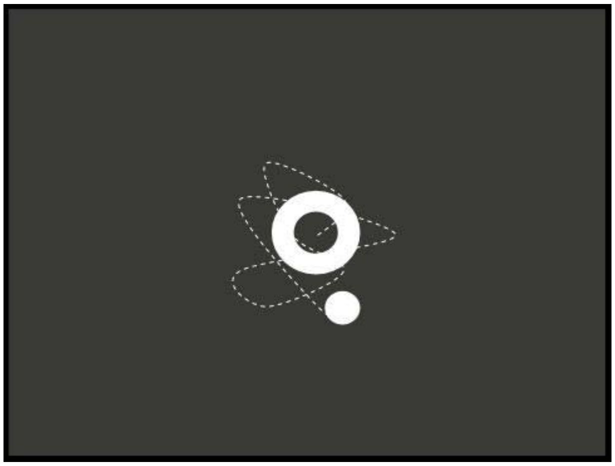


Figure 1. Driving analog task. Screen shot (simulated) of visual tracking task

2. Results

We have plotted the eye movements of a subject during the three tasks: the Paced Auditory Serial Addition Task (PASAT) in Figure 2, the visual tracking task in Figure 3, and the combined PASAT + tracking task in Figure 4. Horizontal and vertical axes are the X coordinate and the Y coordinate of the position of the left eye (in red) and the right eye (in blue) gaze directions on the monitor screen in front of the subject, measured in pixels. The vertical axis is the time from the start to the finish of the tasks, in milliseconds.

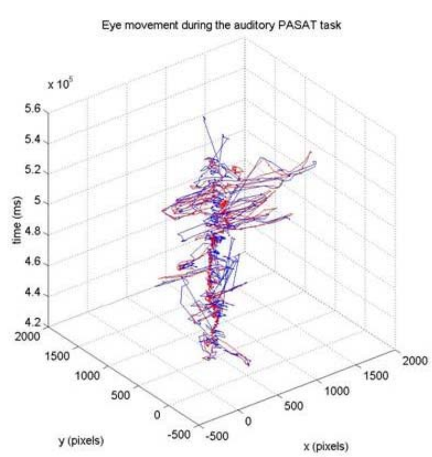


Figure 2 Eye movement during the auditory Paced Auditory Serial Addition Task (PASAT) task. Horizontal axes are the X coordinate and the Y coordinate, respectively, of the position of the left eye (in red) and the right eye (in blue) gaze directions on the monitor screen in front of the subject, measured in pixels. The vertical axis is the time from the start to the finish of the tasks, in milliseconds.

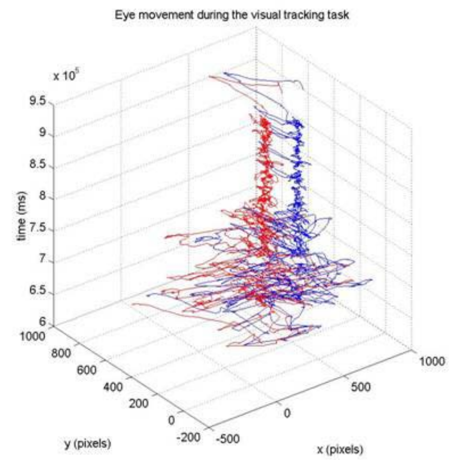


Figure 3. Eye movement during the visual tracking task. Horizontal axes are the X coordinate and the Y coordinate respectively. of the position of the left eye (in red) and the right eye (in blue) gaze directions on the monitor screen in front of the subject, measured in pixels. The vertical axis is the time from the start to the finish of the tasks, in milliseconds.

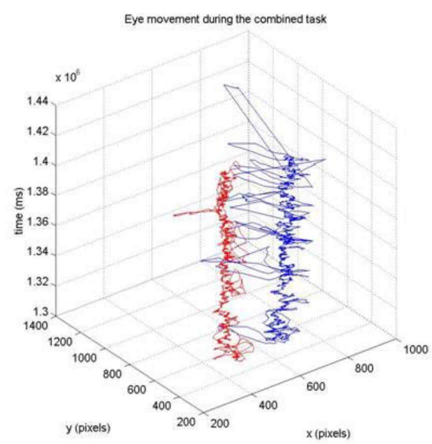


Figure 4. Eye movement during the combined PASAT-and-tracking task. Horizontal axes are the X coordinate and the Y coordinate respectively. of the position of the left eye (in red) and the right eye (in blue) gaze directions on the monitor screen in front of the subject, measured in pixels. The vertical axis is the time from the start to the finish of the tasks, in milliseconds.

Comparing Figures 2 and 3 for the two single tasks we see that during the auditory task the movements of the two eyes hover in a region of the screen without fixating upon any particular location. Also in figure 2., the movements of the two eyes are quite random and completely superimpose each other.

In comparison, during the visual task (figure 3) the total extent of excursion is smaller (by about half) than for the auditory task (note change in scale). As in the auditory task, the eyes also remain well coordinated. It is worth noting, however, that in the auditory task, even though the eyes are free to roam anywhere since there is nothing of relevance to task performance in the visual field, they tend to hover in a rather small region of the visual field (without fixating at any point in particular.) This seems consistent with the finding that when people are paying attention (in this case, to an auditory/cognitive task) their gaze narrows down, and consequently, so does their ability to survey their visual environment (visual tunneling).

During the combined visual/auditory task (figure 4.) shows a dramatically reduced extent of eye movements and an apparent increase in the disconjugacy of the two eyes.

The following plots (Figure 5) show the spatial range of the eye movements classified as fixations or smooth pursuits on the screen in front of a representative subject (subject 5) for the two tasks: tracking and combined (for the two numeral presentation ISIs of 240 and 200 ms.) Left eye movements are shown in blue, right eye movements, in red.

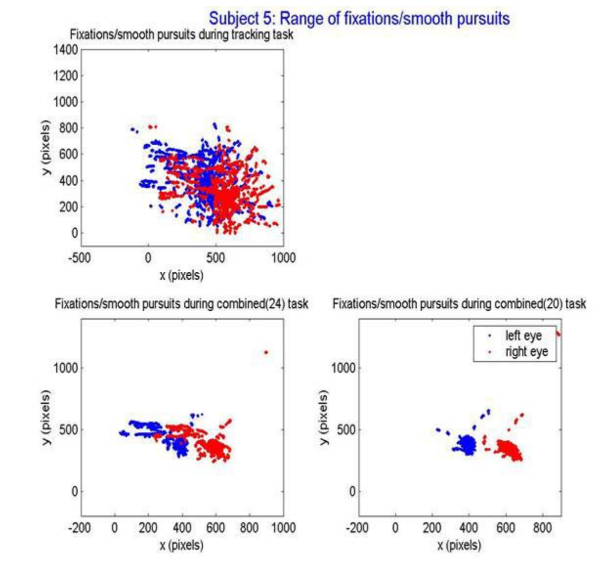


Figure 5. Plot showing the extent in screen coordinates of the eye movement during fixations and smooth pursuits for subject 5. Left eye movements are shown in blue, right eye movements, in red.

All eight subjects showed a reduction in the spatial extent of movements. To quantify the reduction, standard deviations of the spatial extent were calculated.

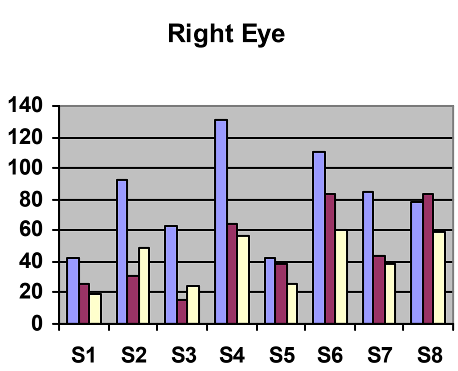


Figure 6. (above) Graph showing the standard deviation of the range of fixation/smooth pursuit eye movements (in pixels) for subjects S1-S8. Blue bars show the data for the tracking task, red, for the combined task with presentation ISI of 240 ms, and yellow, for the combined task with presentation ISI of 200 ms.

Subjects showed on average at least 50% reduction in standard deviation of the spatial extent. Except for subjects 2 and 3 there is more reduction in standard deviation when the numeral presentation ISI is decreased.

The following graph (Figure 7) are the plots of the spatial range of saccadic eye movements, again for subject 5, and the two tasks: tracking and combined (presentation ISI = 240 and 200 ms.). As before, left eye movements are in blue, right eye ones in red.

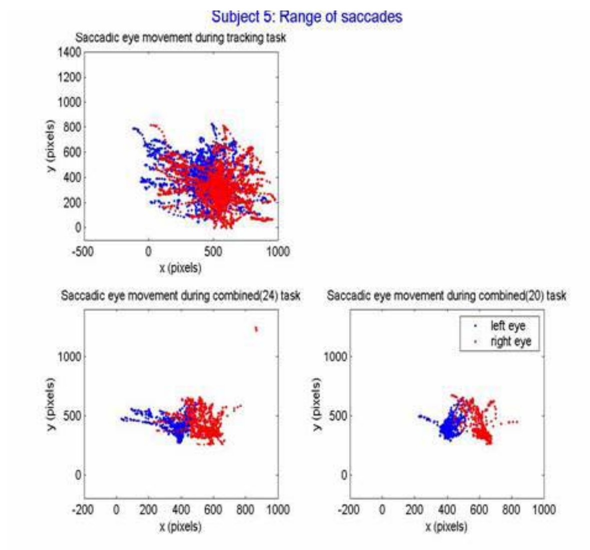


Figure 7. Plots showing the extent in screen coordinates of the eye movement during saccades for subject 5. Left eye movements are shown in blue, right eye movements, in red.

Clearly the same results hold for saccades as for fixations/smooth pursuits: the range over which the eyes roam reduces by about 50% or more as the PASAT task is added to the tracking task.

The consistent reduction in spatial range of both kinds of eye movements as the PASAT is added to the tracking task can be characterized as “visual tunneling”. A possible explanation for the effect is as follows: The cognitive effect of adding the PASAT task to the tracking task is an increase in cognitive load, and therefore, an increase in attentional resources demanded of the subjects. Further, the greater the presentation speed in the PASAT task, there will be an additional increase in attentional demand. The increased attentional demand results in focusing of visual attention to a smaller portion of the visual field, that portion, in fact, that is most essential to the performance of the visual task. Excursions to other areas of potential visual interest are minimized. This reduction of movement would come at the price of reducing the ability to detect peripheral items of interest.

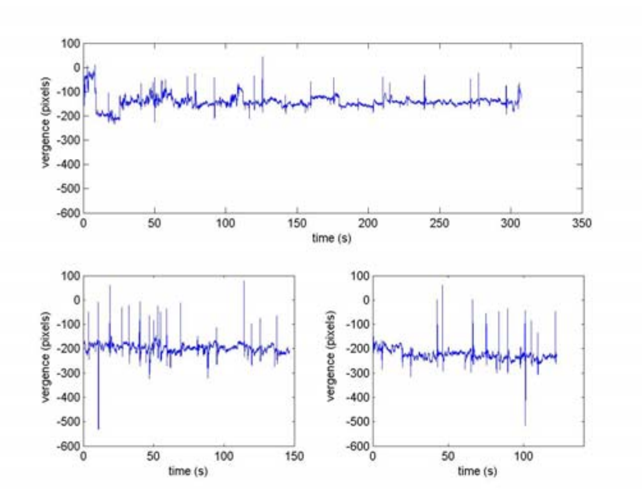
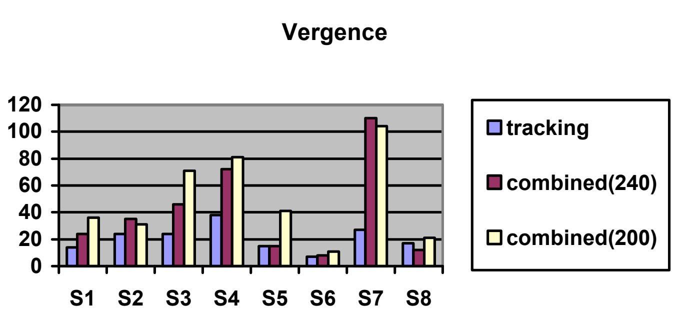


Figure 8. Vergence angle (angle between right and left eyes) on tracking alone (upper) and Tracking + auditory task (ISI 240ms, lower left and ISI 200ms, lower right)

The angle between the two eyes as they move is called the vergence angle. This angle increases as objects are closer to the eyes. Vergence control is a different oculomotor command system than other eye movements. Figure 8 (above) shows that there is greater variability in vergence angle as the dual tasks are performed. This particularly occurs during saccadic refixations, which appear as "spikes" in the figure. Figure 9 shows the increase in standard deviation of the vergence angle as the auditory tasks are added.

Figure 9 (below): Chart showing the standard deviation of the vergence *(difference between the left and right eye x-coordinates*, in pixels) for subjects S1-S8. Blue bars show the data for the tracking task, red, for the combined task with presentation ISI of 240 ms, and yellow, for the combined task with presentation ISI of 200 ms.



3. Impact

Changes in oculomotor behaviour appear to signal a change in operator workload. An important question for further research is to determine if the changes are task specific or are more fundamentally related to the workload condition. For example, visual tunneling of attention might not be all there is to explaining reduction in amplitude of smooth pursuits. It is conceivable that with the periodic engagement of attention by the PASAT task, the ability of the visual system to smooth-pursue the cursor is reduced. The task of tracking the cursor in this situation is accomplished mostly by saccades. At moments of loss of attention to the PASAT task, the eyes either fixate or may roam at random showing high vergence variability.

Although previous studies have demonstrated general eye activity changes with shifts in task demand, few studies have attempted to combine multiple eye measures or utilize sufficiently short (sub 1 minute) integration times. Both of these analytic methods appear to be required in a system that would contribute to real-time workload estimation. Recent studies by Van Orden, Limbert, Makeig, and Jung [1] and Van Orden, Jung, and Makeig [2], on eye activity correlates of fatigue successfully estimated performance in a sustained visual tracking task by combining 60-s moving-window estimates of eye activity. In our dual-task condition a similar signal-processing approach could be used to analyze eye data during a task in which memory and visual activity demands are varied over time. The accuracy of models combining eye measures in predicting moment-to-moment fluctuations in task demand could be assessed in future work.

4. Acknowledgements

Our thanks to SID Information Display International Symposium for allowing us to modify templates they had developed for their Digest of Technical Papers.

5. References

[1] Van Orden K., Limbert W., Makeig S., and Jung T-P, "Eye Activity Correlates of Workload during a Visualspatial Memory Task", Human Factors, 43(1):111-21, 2001.

[2] Van Orden K, Jung T-P, and Makeig S, "Combined eye activity measures accurately estimate changes in sustained visual task performance," Bio Psych, 52:221-40, 2000

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